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Signal delaying device and method for dynamic delaying of
a digitally sampled signal

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The invention relates to a signal delaying device and a
method for dynamic delaying of a digitally sampled
signal.

10 For instance, in the context of signal generators, which
generate mobile telephone signals, there is a need for a
dynamic delay of the signals present in digital form in
the base band, for example, in order to simulate dynamic
fading. Dynamic fading is a typical channel property of
15 mobile telephone transmission routes, in which the
shading and reflection conditions of the mobile telephone
device moving spatially over the transmission route are
constantly changing. In signal generators used in mobile
telephone measuring technology, this dynamic signal delay
20 must therefore be simulated in the base band
conditioning. In this context, dynamic delaying means
that the time delay experienced by the signal is not
constant but changes dynamically. The signal generator
therefore provides a signal delaying device in the base
25 band, which forms the subject matter of the present
invention. The base-band conditioning and the arrangement
of the signal delaying device according to the invention
may, for example, be found as a whole in document DE 101
24 372 A1, where the signal delaying device is described
30 as a fading unit (Fad A, Fad B).

If only a static delay is to be provided in the signal
delaying device, this is not problematic. An accurately
delayed sampled value is produced with a constant delay

for every sampled value of the input signal. If this is adequate in terms of accuracy, it is sufficient, to write the sampled values of the input signal into a cyclical memory, for example, into a RAM (Random Access Memory), and to read them out with a cyclical delay. A cyclical memory arrangement of this kind for a fading simulator is known, for example, from DE 101 08 922 A1. To increase accuracy, an interpolation element, which interpolates either in a linear manner, or more generally with a higher-order function between two output sampled values of the cyclical memory, can be connected in series to the cyclical memory.

A problem occurs, if the delay is not static, i.e., constant, but dynamic or variable over time. If the additional delay relative to the output sampled value of the cyclical memory caused by the interpolation increases over time, this means that, in a region defined by two successive sampled values read out from the memory, not only one intermediate value, but two intermediate values must be interpolated. An over-range of this kind does not in itself present an actual problem. While a new value is being written into the memory, no new value is read out from the memory, so that the interpolation element then once again carries out an interpolation with the same sampled values, but with different interpolation coefficients, which correspond to the new, second interpolation position.

However, an actual problem arises, if the additional delay caused by the interpolation decreases over time and therefore no interpolation value falls into a range between two successive output sampled values of the memory, and instead, the next interpolation value already

falls into the next range between the next two adjacent output sampled values of the memory. This is problematic because in this case, two output values would have to be read out from the memory at the same time. This is not possible in the case of conventional memories with one read gate and one write gate. More complex memories with one write gate and two read gates are indeed available; however, these memories are considerably more expensive and would significantly increase costs. Even the solution proposed in DE 101 08 922 A1 with read fifo-memories connected in series to the memory would considerably increase costs.

The present invention is therefore based upon the object of providing a signal delaying device and a method for delaying a digital signal, which allows dynamic signal delaying at a low implementation cost even in the event of an over-range or an under-range.

This object is achieved, with reference to the signal delaying device, by the features of claim 1; and with reference to the method, by the features of claim 6.

The invention is based upon the knowledge that instead of a cost-intensive increase of access to the memory element, it is advantageous to provide the additional sampled value required in the case of an under-range, in a register arranged in parallel to the memory element. If the lower range threshold is reached, the register with the additional sampled value is loaded and can be read out, whenever the appropriate sampled value has arrived at the output of the memory element.

The dependent claims relate to advantageous further embodiments of the invention.

After a sampled value has been stored in the register,
5 the next sampled value, which is again supplied to the memory element, is advantageously marked, for example, by a bit of the word width of the memory element, which has not been defined by the data width. Whenever the marked sampled value reaches the output of the memory element,
10 this can be recognised by the marking, and this marked sampled value can be read out from the memory element, and also the additional sampled value from the register can be supplied to the interpolation element, so that the next interpolation is not implemented in the next range
15 but in the next range but one. However, marking of this kind is not compulsory for the realisation of the invention. Because the runtime through the memory element is essentially known, it would be possible to register by means of a procedure control - which would generally
20 require greater complexity - , when the sampled value immediately following the sampled value stored in the register has arrived at the output of the memory element. The runtime through the memory results from the unconditioned delay desired, it does not depend upon the
25 memory capacity.

The interpolation element advantageously consists of a polyphase filter, to which a half-band filter is connected in series in order to reduce costs.

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The invention will be described in greater detail below with reference to the drawings. The drawings are as follows:

- Figure 1A shows a time line for the visualisation of a static delay;
- Figure 1B shows a time line for the visualisation of a dynamic delay with an over-range;
- Figure 1C shows a time line for the visualisation of a dynamic delay with an under-range;
- Figure 2 shows an exemplary embodiment of the signal delaying device according to the invention in a first condition;
- Figure 3 shows an exemplary embodiment of a signal delaying device according to the invention in a second condition;
- Figure 4 shows an exemplary embodiment of the signal delaying device according to the invention in a third condition;
- Figure 5 shows an exemplary embodiment of the signal delaying device according to the invention in a fourth condition;
- Figure 6 shows an exemplary embodiment of the signal delaying device according to the invention in a fifth condition;
- Figure 7 shows a flow diagram for the explanation of the method according to the invention and

Figure 8 shows a time line for the explanation of the function of the half-band filter and the polyphase filter.

5 The essential structure of the signal delaying device 1 will be described with reference to Figure 2, after which the problem upon which the present invention is based will be explained with reference to Figures 1A to 1C.

10 A digitally sampled input signal $S_{in}(k)$ is supplied to a memory element 2. The input signal $S_{in}(k)$ is stored in a cyclical manner in the memory element 2. To a certain extent, the memory element produces an unconditioned delay. After this unconditioned delay, the corresponding

15 sampled value is read out from the memory element 2 and supplied to an interpolation element 3, which, in the exemplary embodiment illustrated, consists of a half-band filter 4 connected in series to the memory element 2 and a polyphase filter 5 connected in series to the half-band

20 filter 4.

In the exemplary embodiment illustrated, the polyphase filter 5 consists of a first delaying element 6_1 , a second delaying element 6_2 and a third delaying element 6_3 , a

25 first multiplexer 7_1 , a second multiplexer 7_2 , a third multiplexer 7_3 , a fourth multiplexer 7_4 , a fifth multiplexer 7_5 . While the fifth multiplexer 7_5 has a special function to be described below, the first multiplexer 7_1 is used for switching between the input of

30 the first delaying element 6_1 and the input of the second delaying element 6_2 . The second multiplexer 7_2 is used for switching between the input of the second delaying element 6_2 and the output of the first delaying element 6_1 and/or the input of the third delaying element 6_3

connected in series to the first delaying element 6_1 . The third multiplexer 7_3 is used for switching between the input of the third delaying element 6_3 and the output of the second delaying element 6_2 . By contrast, the fourth
 5 multiplexer 7_4 is used for switching between the output of the second delaying element 6_2 and the output of the third delaying element 6_3 .

The outputs of the multiplexers 7_1 to 7_4 are connected to
 10 multipliers 8_1 to 8_4 . Moreover, each of the multipliers 8_1 to 8_4 is connected to a coefficient memory 9_1 to 9_4 , in which several readable multiplication coefficients I_0 to I_3 are stored. After the less significant bits of the output signals from the multipliers 8_1 to 8_4 have been cut
 15 off, these output signals are supplied in pairs to a first addition element 10_1 and a second addition element 10_2 , while the outputs of the addition elements 10_1 and 10_2 are again summated in the third addition element 10_3 to form a complete signal. After rounding in a rounding
 20 element 11 , the output signal $S_{out}(k)$ is provided as an interpolated sampled value.

The essential method of operation of the interpolation element 3 will now be explained with reference to Figure
 25 8. Two output sampled values $x(k-1)$ and $x(k)$ of the memory element 2, described as "original values", are illustrated at the left and right-hand edge of the diagram. In addition to these "original values", the half-band filter 4 interpolates an intermediate value
 30 disposed exactly in the centre with reference to time. Figure 8 shows the three output values $y(2k-3)$, $y(2k-2)$ and $y(2k-1)$ of a half-band filter 4. At 10 equidistant polyphases p_0 to p_9 , the polyphase filter 5 shown in the exemplary embodiment interpolates between the output

values produced by the half-band filter 4. The decision regarding at which of the ten different polyphases p_0 to p_9 , the interpolation is carried out, depends on the coefficients read out from the coefficient memories 9_1 to 9_4 . The desired polyphase is adjusted via the address "Read Control" in Figure 2. Since the uneven output values $y(2k-1)$ and the even output values $y(k2)$ are output from the half-band filter 4 separately, and supplied to separate delaying chains, it is possible to switch between the ranges "range 1" and "range 2", as shown in Figure 8, by switching the multiplexers 7_1 to 7_4 .

Accordingly, with reference to the output values $x(k)$ of the memory element 2, twenty equidistant intermediate values can be interpolated in an optionally switchable manner. This allows the possibility of fine-tuning of the signal delay produced overall by the signal delaying device 1. In the example shown in Figure 8, the input signal $S_{in}(k)$ has a sampling rate of 100 MHz, i.e., the sampling period is 10ns. Accordingly, an unconditioned delay of a multiple of 10ns is produced by the memory element 2. With the half-band filter 4 and the polyphase filter 5, a fine-tuned delay is additionally possible on a grid of 0.5 ns, thereby considerably increasing the accuracy of the adjustable delay.

The problem upon which the invention is based will now be explained with reference Figures 1A to 1C. In each case, the diagram illustrates a number of "original values" $x(k)$ at the output of the memory element 2 and interpolated intermediate values $S_{out}(k)$ produced from these.

Figure 1A initially illustrates the case of a static delay. One output sampled value $S_{out}(k)$ from the interpolation element 3 corresponds exactly to each output sampled value $x(k)$ of the memory element 2. This case is unproblematic.

Figure 1B illustrates a case in which the delay τ caused by the signal delaying device 1 increases with time t , i.e., the delay intervals τ_1 to τ_6 become increasingly larger. Within the range 20 limited by the output sampled values $x(k-4)$ and $x(k-3)$ of the memory element 2 and shaded in grey in Figure 1B, there are not only one but, in fact, two output sampled values $S_{out}(k-3)$ and $S_{out}(k-2)$. Within the context of the present application, this case is described as an over-range. This does not represent a particularly difficult problem and can be resolved using a RAM with only one write gate and one read gate in that a new sampled value is indeed stored in the memory element 2, i.e., the write pointer is adjusted, for example, incremented, but no new sampled value $x(k)$ is read out from the memory element 2; in other words, the read pointer is not adjusted. As a result, the half-band filter 4 and the polyphase filter 5 can implement another interpolation with the same output values, but this time at a different interpolation position, that is to say, with a different range, "range 1" and "range 2" from Figure 8, and/or with a different polyphase p_0 to p_9 . In the case of an over-range, the unconditioned delay of the memory element 2 is increased by one system-clock period.

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Figure 1C shows a more complicated case in which the delay τ produced by the signal delaying device 1 decreases over time t , i.e., the delay intervals τ_1 to τ_5 become progressively smaller. In the example shown in the

present case, the interpolation value $S_{out}(k-2)$ does not lie within the range 21, which is limited by the sampled values $x(k-4)$ and $x(k-3)$ at the output of the memory element 2; it lies in the following range 22, which is limited by the sampled values $x(k-3)$ and $x(k-2)$. The calculation of $S_{out}(k-2)$ is therefore based on two new sampled values at the output of the memory element 2. With conventional implementation, this would mean that two output values would have to be read out from the memory element at the same time. This could only be achieved with a relatively expensive RAM with two read gates or alternatively with two RAM memory components arranged in parallel and containing identical information. Both of these solutions would be extremely cost-intensive and are therefore highly disadvantageous.

In order to resolve this problem, the present invention proposes the arrangement of a register 30, as illustrated in Figure 2, in parallel to the memory element 2, which, in the presence of a release signal "enable" stores a sampled value $S_{in}(k)$ of the input signal, and which is connected to the output side of the interpolation element 3, in the exemplary embodiment, to the half-band filter 4. Moreover, "range 2" from Figure 8 is supplemented by the polyphase p_{10} .

The collaboration between the register 30, the memory element 2 and the interpolation element 3 will be described below with reference to Figures 2 to 6. Different processing conditions are illustrated in each case. Active conductors are shown as continuous lines; non-active conductors are shown as broken lines.

Figures 2 and 3 initially show the normal operation of the signal delaying device 1 without activation of the register 30. At each system-clock pulse, one sampled value for each digital input signal $S_{in}(k)$ is written into the memory element 2 by the control signal "Read & Write Control", and a sampled value $x(k)$ corresponding to the unconditioned delay is read out. Figures 2 and 3 differ from one another in that, in the case of Figure 2, an interpolation is implemented within "range 1" as shown in Figure 8; in Figure 3, an interpolation is implemented within "range 2" from Figure 8. This is achieved by a corresponding switching of the multiplexers 7_1 to 7_4 . The multiplexer 7_5 is connected in both cases in such a manner that uneven output sampled values $y(2k-1)$ can be supplied to the delaying element 6_2 . The required set of coefficients is selected in the memories 9_1 to 9_4 with the address "Read Control" to correspond with the desired polyphase. If the range is exceeded as illustrated in Figure 1B, only one new sampled value $S_{in}(k)$ is written into the memory element 2, but no sampled value $x(k)$ is read out.

When the lower range limit from Figure 8 is reached at 0 ns, the register 30 is activated by the release signal "Enable", as shown in Figure 4. At the same time, the write gate of the memory element 2 is deactivated. The next sampled value $S_{in}(k)$ of the input signal is therefore not stored in the memory element 2 but rather in the register 30. Accordingly, the unconditioned delay of the memory element 2 is reduced by one system-clock period. By contrast with the case of an over-range, in this case, the interpolation element 3 is initially not affected by this change, because the change was implemented at the input of the memory element 2 and not at its output.

Figure 5 shows that in the next system-clock pulse, the next sampled value $S_{in}(k)$ is again stored in the memory element 2, however, this time a marking is added to the sampled value. A marking device 31 is shown symbolically in the present context. The marking device 31 is generally not physically present, but represents a component of the central processor. A bit of the word width of the memory element 2, which is not required for the data word, can be used for marking. The marking runs through the memory element 2 together with the marked sampled value. The interpolation element 3, in the exemplary embodiment, the half-band filter 4, registers when the marking is present at the output of the memory element.

Figure 6 illustrates a case in which the marking appears at the output of the memory element 2 and is recognised by the interpolation element 3. In this case, the multiplexer 7₅ is switched over, and an additional sampled value is produced by the half-band filter 4, which is supplied to the delaying element 6₂ instead of the uneven sampled value $y(2k-1)$. The interpolation element 3 therefore carries out an interpolation on the basis of two new input values. One input value was read out from the memory element 2. The other input value was placed in intermediate storage in the register 30 until the occurrence of the marking and then read out from the register.

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The simultaneous reading in of two new values into the interpolation element 3, effectively reduces the delay by one system-clock period. However, since an under-range has not so far occurred, but, when the lower range limit

is reached, only the possibility of a future under-range is given, the delay must again be compensated by one system-clock period by immediately switching the polyphase from p_0 in "range 1" to p_{10} in "range 2".

5 Overall, nothing has yet changed in the delay, but the preparations for an actual under-range, i.e., changing the polyphase from p_{10} to p_9 in "range 2" are already complete.

10 Figure 7 once again illustrates the method according to the invention with reference to a flow diagram.

Normal operation is illustrated in stage S100, that is to say, at every system-clock pulse, the write pointer,
15 which points to the next memory cell of the memory element 2 to be described below, is adjusted (e.g. incremented). The read pointer is correspondingly adjusted, e.g. incremented to the next memory cell of the memory element 2 to be read out.

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In stage S101, a test is run to determine whether the lower range limits, that is, the polyphase p_0 in "range 1" from Figure 8, has been reached. If this is not the case, an under-range as shown in Figure 1C can be excluded. In
25 stage S102 a check must be carried out to determine whether an over-range has occurred instead, i.e., a change from polyphase p_{10} in "range 2", with an additional delay of 10 ns in this example caused by the interpolation, to polyphase p_0 in "range 1" from Figure 8
30 with an additional delay of 0.5 ns caused by the interpolation. If this is not the case, then the flow diagram again branches to stage S100.

However, if an over-range is indeed present, only the write pointer, but not the read pointer of the memory element 2 will be adjusted in stage S103. As a result of this measure, the delay caused by the memory element 2 is
 5 prolonged.

At the same time, the slide registers of a half-band filter 4 and the delaying elements 6_1 , 6_2 and 6_3 of the polyphase filter 5 must be deactivated, so that these do
 10 not continue to shift by one clock pulse. After a second interpolation has been carried out in the same range 20 in Figure 1B with the new polyphase, the flow diagram again branches to stage S100.

15 By contrast with the above, if it is determined in stage S101 that an under-range is present, then, initially in stage S104, which corresponds to Figure 4, a sampled value $S_{in}(k)$ is loaded into the register 30 instead of into the memory element 2. In this context, the write
 20 pointer of the memory element 2 is naturally not adjusted. However, since a sampled value is read out from the memory element 2 at the same time, the read pointer must be adjusted. As a result of this measure, the delay caused by the memory element 2 is reduced. Stage S104 is
 25 represented in Figure 4.

In stage S105, which corresponds to Figure 5, in the next system-clock pulse, both the write pointer and the read pointer are adjusted, but the next sampled value to be
 30 written into the memory element 2 is provided with a marking.

In stage S106, normal operation is continued until it is determined in stage S107 that the marking has arrived at

the output of memory element 2. This means that the additional value stored in the register 30 together with the sampled value $x(k)$ present at the output of the memory element 2 can now be supplied to the delaying
5 element 6₂ of the polyphase filter 5 via the half-band filter 4 and the multiplexer 7₅, as illustrated in Figure 6. The polyphase is changed from 0 ns to 10 ns.

It must still be pointed out that the runtime of the
10 marked sampled value through the memory element 2 is irrelevant, because the system-clock pulse is substantially greater than the time change in the delay time. In other words, for a given polyphase, a large number of sampled values are interpolated, before
15 changing to the next polyphase. Within this time, the marked sampled value will have arrived at the output of the memory element 2 with a high degree of certainty. In Figures 1B and 1C, the changes in the delay time are illustrated in an exaggerated manner merely for improved
20 illustration.

The invention is not restricted to the exemplary embodiment presented. For example, as already mentioned, instead of marking, another procedural control could
25 monitor when the sampled value, which follows the sampled value stored in the register 30, has arrived at the output of the memory element 2.